UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PIPELINE ORIFICE STUDIES
COACHELLA DISTRIBUTION SYSTEM
ALL-AMERICAN CANAL PROJECT

Hydraulic Laboratory Report No. 202

ENGINEERING AND GEOLOGICAL
CONTROL AND RESEARCH DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

APRIL 29, 1946

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Laboratory Report No. 202
Hydraulic Laboratory
Written by: Fred Locher
Reviewed by: J. N. Bradley

Subject: Pipeline orifice studies—Coachella distribution system—All-American Canal System.

INTRODUCTION

The Coachella distribution system will convey the water to the various irrigated tracts through a covered precast concrete piping system. In general, it was proposed to use weirs for measuring the pipe flow and as baffles for the diversion of water to turnouts upstream from the weir where no demand for water downstream thereof existed. The turnouts include a measuring device for metering the flow to individual users. Some of the mainline measuring weirs become quite large and as a considerable number of them would be required, it seemed advisable to consider some other means of measuring the pipeline flow. It appeared that the pipeline orifice might prove satisfactory as well as reduce the initial cost of the installation and for this reason, studies were instigated to determine the applicability of the orifice.

THE SCOPE OF STUDY

The study consisted of evaluating the head losses across various orifices for the applicable range of prototype discharges and determining the approximate differential gage readings for the maximum and minimum flows. In addition, a 3-inch orifice was placed in a 6-inch pipe and tested with and without a deposit of sediment against the upstream orifice face.

THE MODEL

The model for determining the effect of deposits immediately upstream of the orifice plate consisted of a length of 6-inch transparent pipe with a 3-inch orifice at the downstream end. The transparent pipe was connected to a 6-foot length of 6-inch brass pipe, which in turn, was connected to the laboratory metering system.

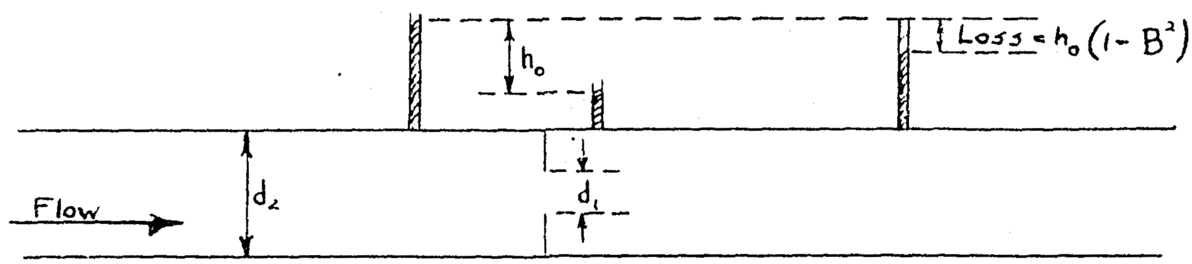
THE INVESTIGATION

The laboratory investigation consisted of (1) calibrating the orifice without sediment or other foreign material in the pipe; (2) repeating the procedure with the pipe filled with sand to the lower edge of the orifice; and (3) the calibration of the orifice with a triangular wedge of molding clay placed immediately upstream of the orifice to simulate a bonded sediment.

The head-discharge and the coefficient curves for flow with no sediment in the pipe are shown on Figure 1. Similar curves for discharge with the clay filler in the pipe are also shown on Figure 1. The clay filler definitely increased the coefficient of discharge. The maximum coefficient for the clean pipe was 0.625 and with the clay filler in place it increased to 0.650. This would represent a change in discharge of 3.8 percent for identical heads on the orifice or an error of the same amount in discharge. This would simulate a case in the field wherein the orifice was in an actual installation and later the pipe filled with a bonded sediment.

The tests with unbonded sand in the pipe revealed that at very low heads, as well as at the high heads, the material moved downstream and through the orifice with the material adjacent to the orifice plate moving first. This would indicate that loose silt and sand would not deposit against the orifice and that any loose sediment which might collect at this point, when there was no flow, would move downstream when flow through the orifice was resumed. A coefficient was not obtained for this condition because the sand did not remain long enough to obtain pressure measurements.

The remainder of the investigation involved computing orifice sizes and corresponding pipe sizes, head losses, and pressure differentials for a variety of discharges. This was done as follows:



Referring to the above diagram:

$$B = \frac{d_1}{d_2}$$

The orifice discharge is given by $Q = CA\sqrt{2gh_o}$. Substituting for the area and solving for h_o, the equation becomes $h_o = \frac{8Q^2}{C^2\pi^2 d_1^4 g}$. This when substituted in the loss equation $K = h_o(1 - B^2)$ gives:

$$Q^2 = \frac{gKC^2\pi^2 d_1^4}{8(1 - B^2)} \text{ or}$$

$$Q = C\pi\sqrt{\frac{gK}{8(1 - B^2)}}\, d_1^2$$

By varying B with C according to the following table which was obtained from Trans. A.S.M.E. Volume 58, 1936, Figure 1, Page 595.

B	C
0.30	0.60
0.40	0.61
0.50	0.625
0.60	0.650
0.70	0.690

holding K constant and varying d_1, a family of curves with Q plotted against d_1^2 as shown on Figure 2 was obtained. Since $K = h_o (1 - B^2)$, $h_o = \frac{K}{1 - B^2}$ and as B is constant for a particular curve and K is constant for the family of curves, each curve represents a fixed h_o as well as a constant B. These values are shown on Figures 2 to 6 inclusive.

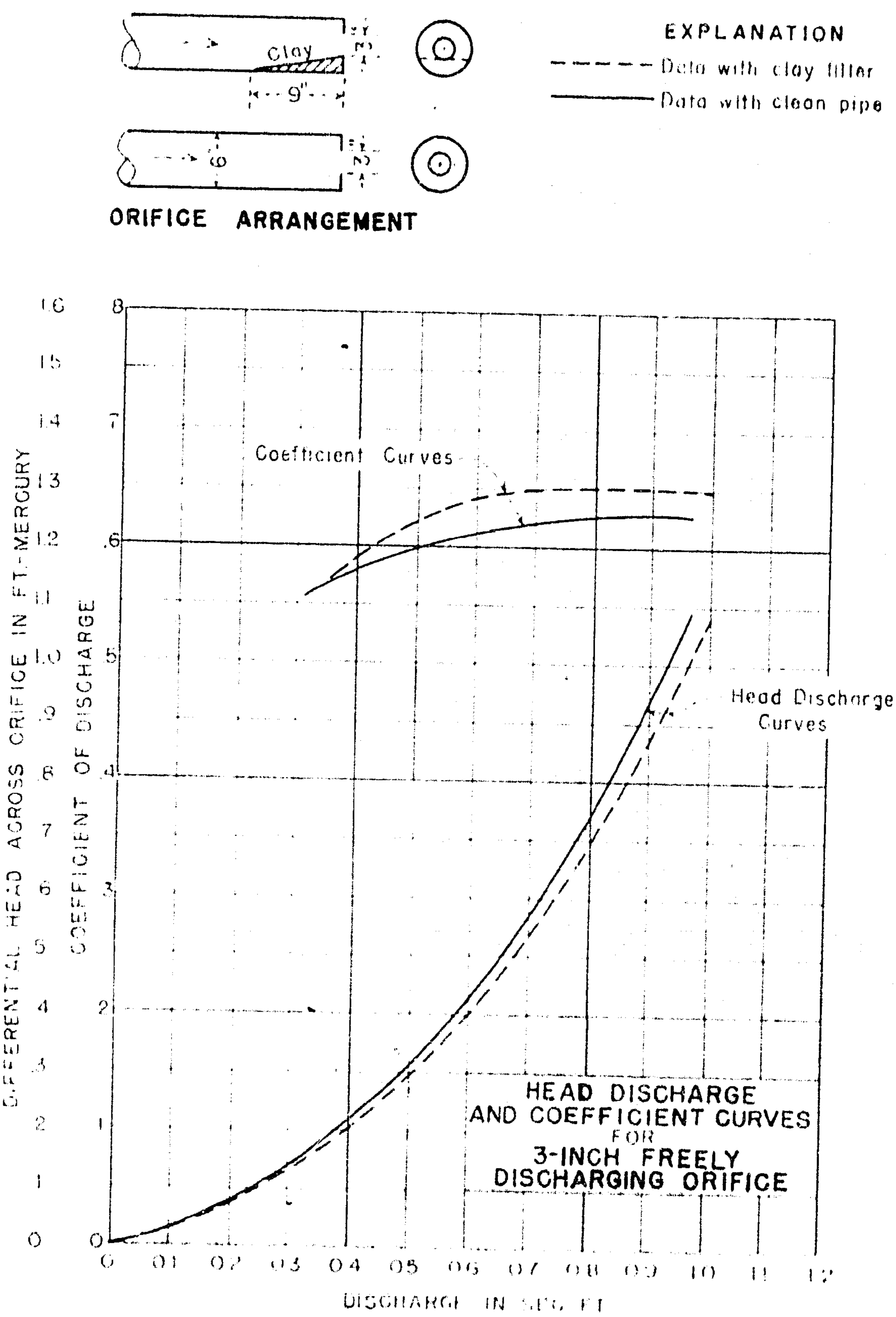
The curves were intended to be used as follows: If the maximum flow in the pipe line is 70 second-feet and if the maximum head loss across the orifice should not exceed 1 foot, then to find an orifice size, enter the curve of Figure 2 on the line showing 70 cfs until it intersects the B lines. From the curves it is possible to obtain five orifice sizes which will have a loss of 1 foot. They are 3.41, 3.69, 3.93, 4.09, and 4.20 feet and have corresponding values of h_o = 1.96, 1.56, 1.33, 1.19, and 1.10. The choice between the five depends upon whether or not the gage reading h_o at minimum discharge will be sufficient to give an accurate indication of the discharge; or if two or more meet this requirement, economic considerations will govern. The gage reading at minimum discharge (assumed to be 10 percent of maximum) was determined from $h_o = \frac{8 Q^2}{C^2 \pi^2 d_1^4 g}$ and gave minimum gage readings as follows: d_1 = 3.41 the min h_o = 0.0192, d_1 = 3.69 the min h_o = 0.0157, d_1 = 3.93 the min h_o = 0.0132, d_1 = 4.09 the min h_o = 0.0118, d_1 = 4.20 the min h_o = 0.0110. All of these differentials are low for an accurate determination of the minimum discharge and indicate that a larger orifice loss is necessary or that the orifice is not practical.

Assuming that the reading of 0.0192 will give sufficient accuracy at minimum discharge then the pipe size is determined from $B = \frac{d_1}{d_2}$; where 0.70 d_2 = 3.41 or d_2 = 4.87 feet. On this basis the measuring section would consist of an orifice 3.41 feet in diameter placed inside of a pipe 4.87 feet in diameter having expanding and reducing sections to conform to the normal pipe line section. In addition a water manometer would be necessary to measure the differential head.

In all, five families of curves were plotted on Figures 2, 3, 4, 5, and 6, which sufficed to cover the typical cases on the Coachella distribution system. These curves were used to determine the orifice size, corresponding head loss, and gage reading for a number of typical metering installations. It was learned that to make the orifices satisfactory they must be submerged for all flows. To accomodate this condition at low flows it would have been necessary to install a baffle in the line with practically every orifice. The baffle loss was equivalent to the weir loss which when added to the orifice loss would have necessitated increasing the pipe diameter over that required for the weir measuring system. The increased cost of the larger pipe added to the cost of a regular orifice measuring section affect the advantages of the orifice to such an extent that the weirs were considered more practical.

CONCLUSIONS

While the orifice is a satisfactory measuring device for use in a pipe line, its use was not suited to the Coachella distribution system because of the necessity of constructing baffle boxes, in connection with the orifices to keep the measuring sections completely filled at all flows. In addition, other baffles similar to a weir were necessary to create sufficient head under certain circumstances to divert flow through turnouts from the main line. The use of these baffles introduced a head loss nearly equal to that obtained from a weir, which when added to the orifice loss, was sufficient to necessitate increasing the pipe size to compensate for the increased loss. The cost of increasing the pipe size greatly offset what first appeared to be an economy. For this reason, and the fact that measuring weirs could also be used as diversion baffles, the weirs were considered superior to the orifices for the Coachella installation.


Clay
9"
6"
ORIFICE ARRANGEMENT
EXPLANATION
Data with clay filler
Data with clean pipe
Coefficient Curves
Head Discharge Curves
DIFFERENTIAL HEAD ACROSS ORIFICE IN FT.-MERCURY
COEFFICIENT OF DISCHARGE
DISCHARGE IN SEC FT
HEAD DISCHARGE AND COEFFICIENT CURVES FOR 3-INCH FREELY DISCHARGING ORIFICE

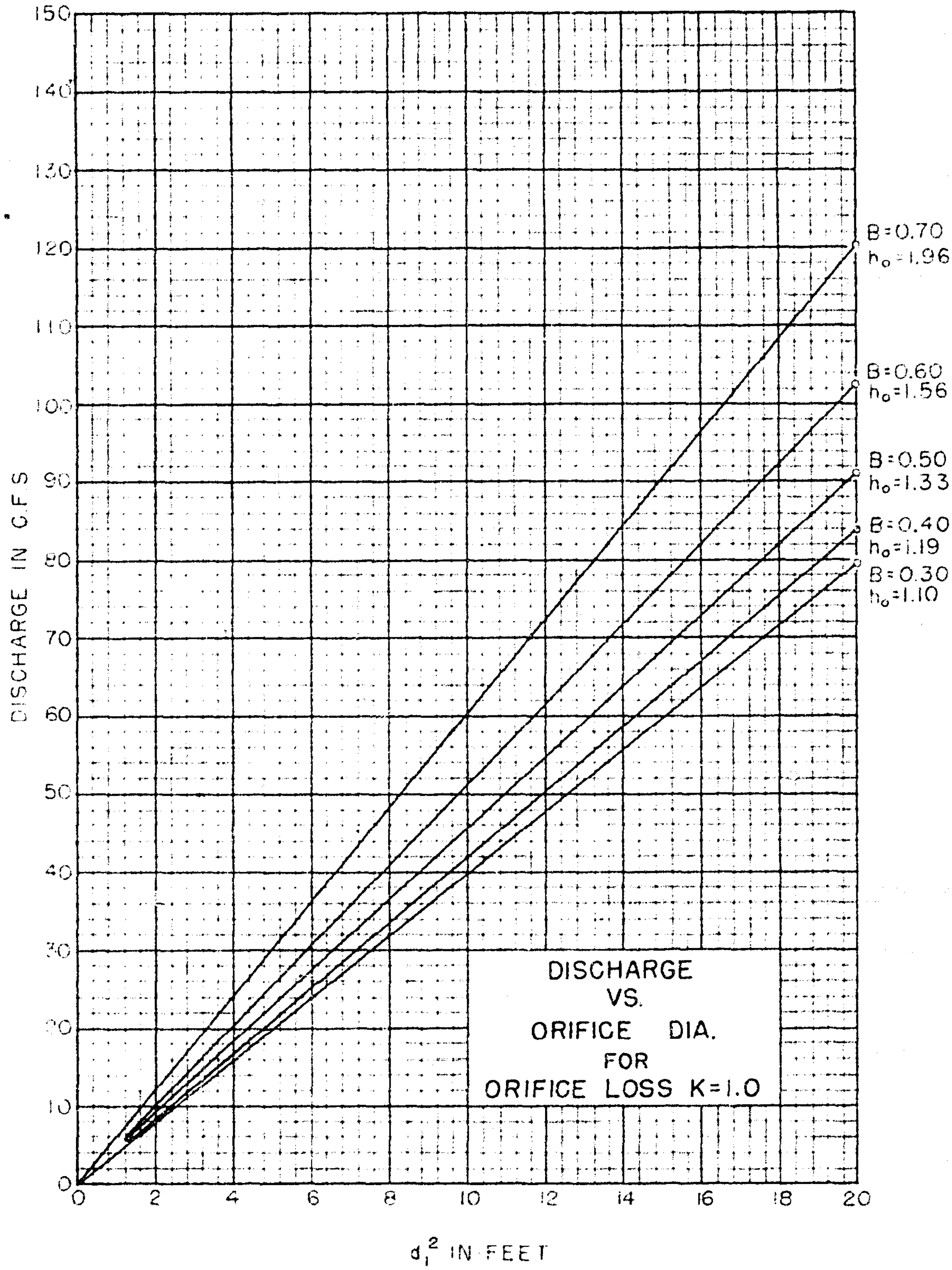

DISCHARGE IN C.F.S.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
d_1^2 IN FEET
0
2
4
6
8
10
12
14
16
18
20
B=0.70
h_o=1.96
B=0.60
h_o=1.56
B=0.50
h_o=1.33
B=0.40
h_o=1.19
B=0.30
h_o=1.10
DISCHARGE
VS.
ORIFICE DIA.
FOR
ORIFICE LOSS K=1.0

FIGURE 3

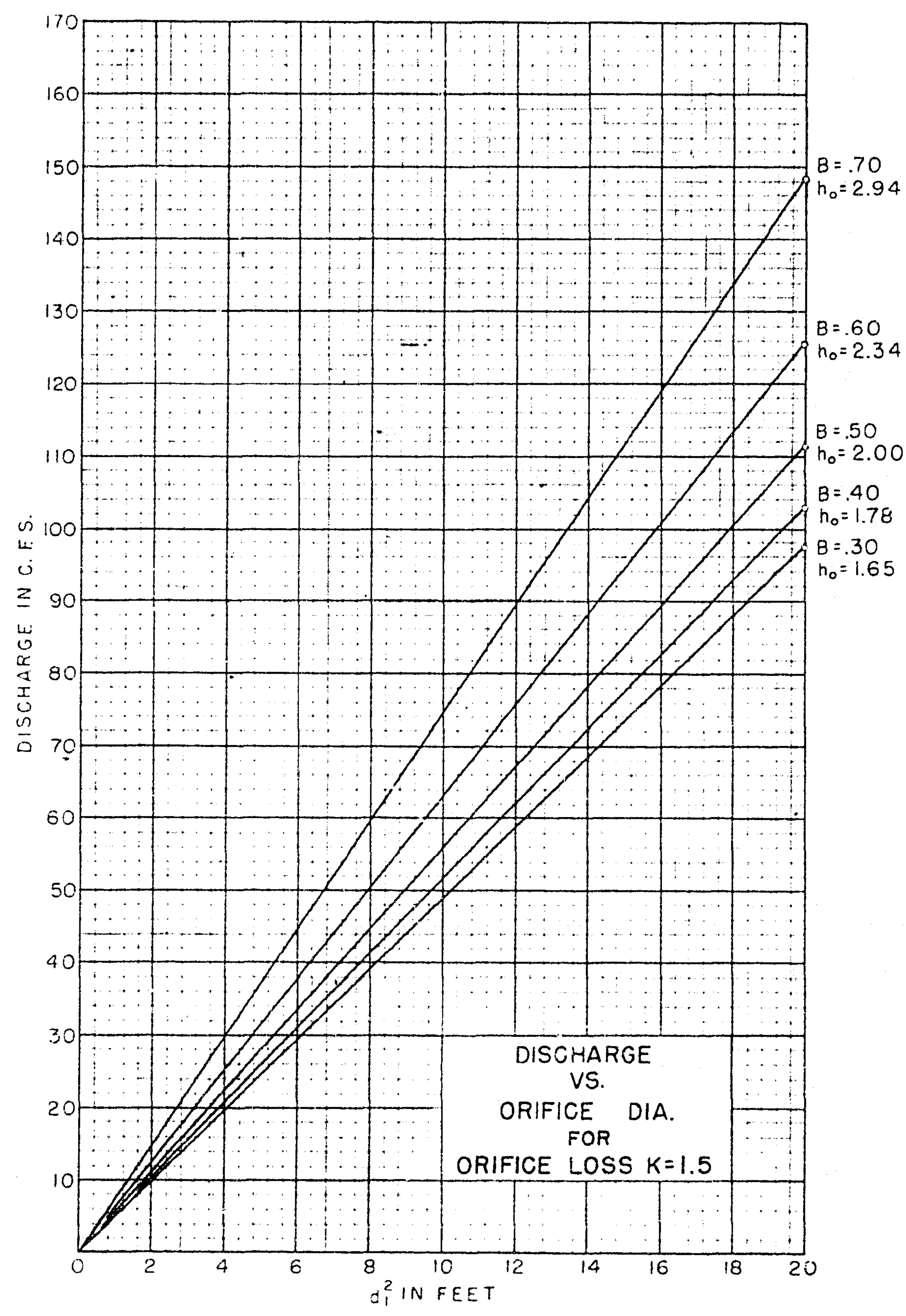
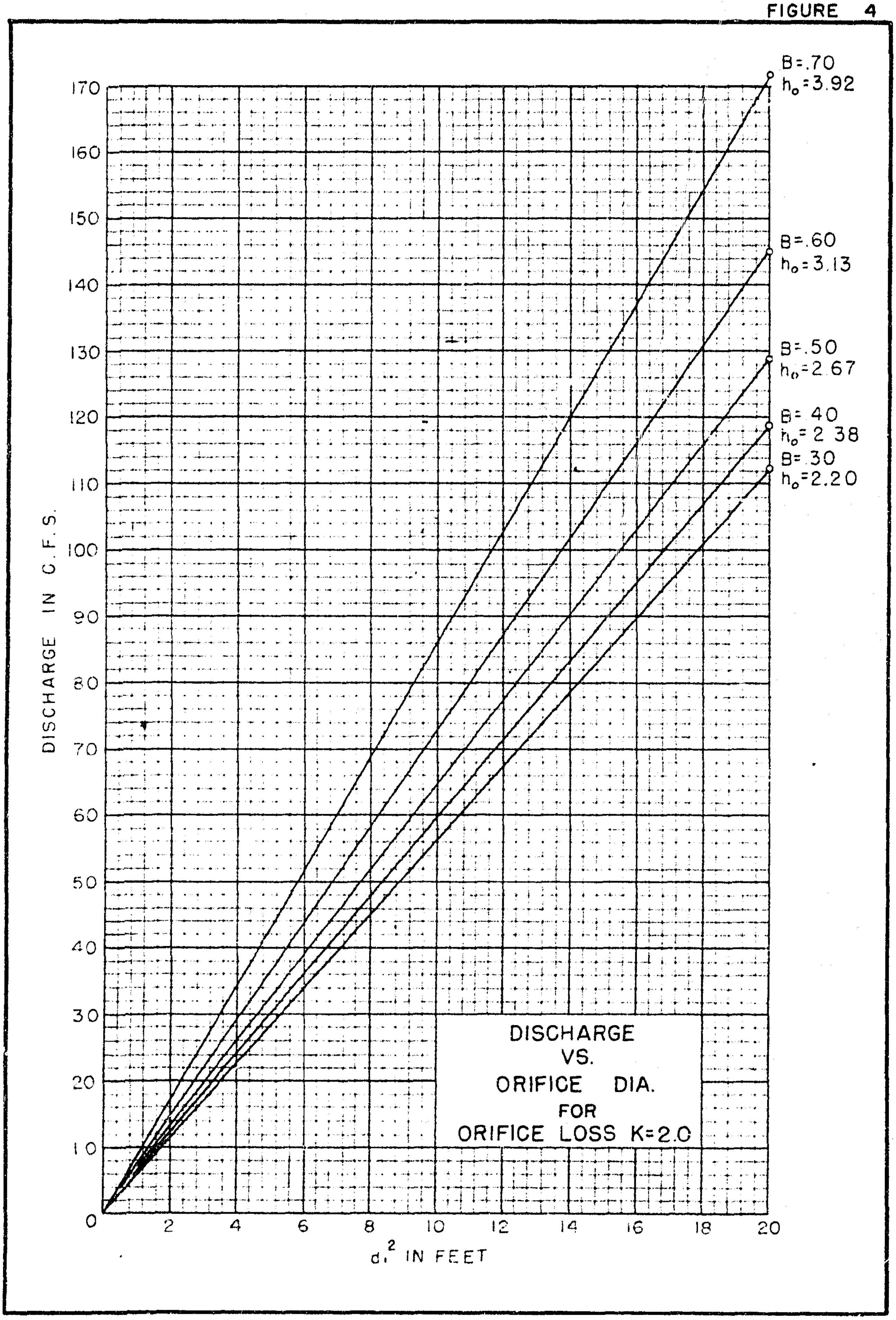

170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
DISCHARGE IN C.F.S.
0
2
4
6
8
10
12
14
16
18
20
d_1^2 IN FEET
B = .70
h_o = 2.94
B = .60
h_o = 2.34
B = .50
h_o = 2.00
B = .40
h_o = 1.78
B = .30
h_o = 1.65
DISCHARGE
VS.
ORIFICE DIA.
FOR
ORIFICE LOSS K=1.5

FIGURE 4



B=.70
h_o=3.92
B=.60
h_o=3.13
B=.50
h_o=2.67
B=.40
h_o=2.38
B=.30
h_o=2.20
DISCHARGE IN C.F.S.
d_1^2 IN FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
2
4
6
8
10
12
14
16
18
20
DISCHARGE
VS.
ORIFICE DIA.
FOR
ORIFICE LOSS K=2.0

FIGURE 5

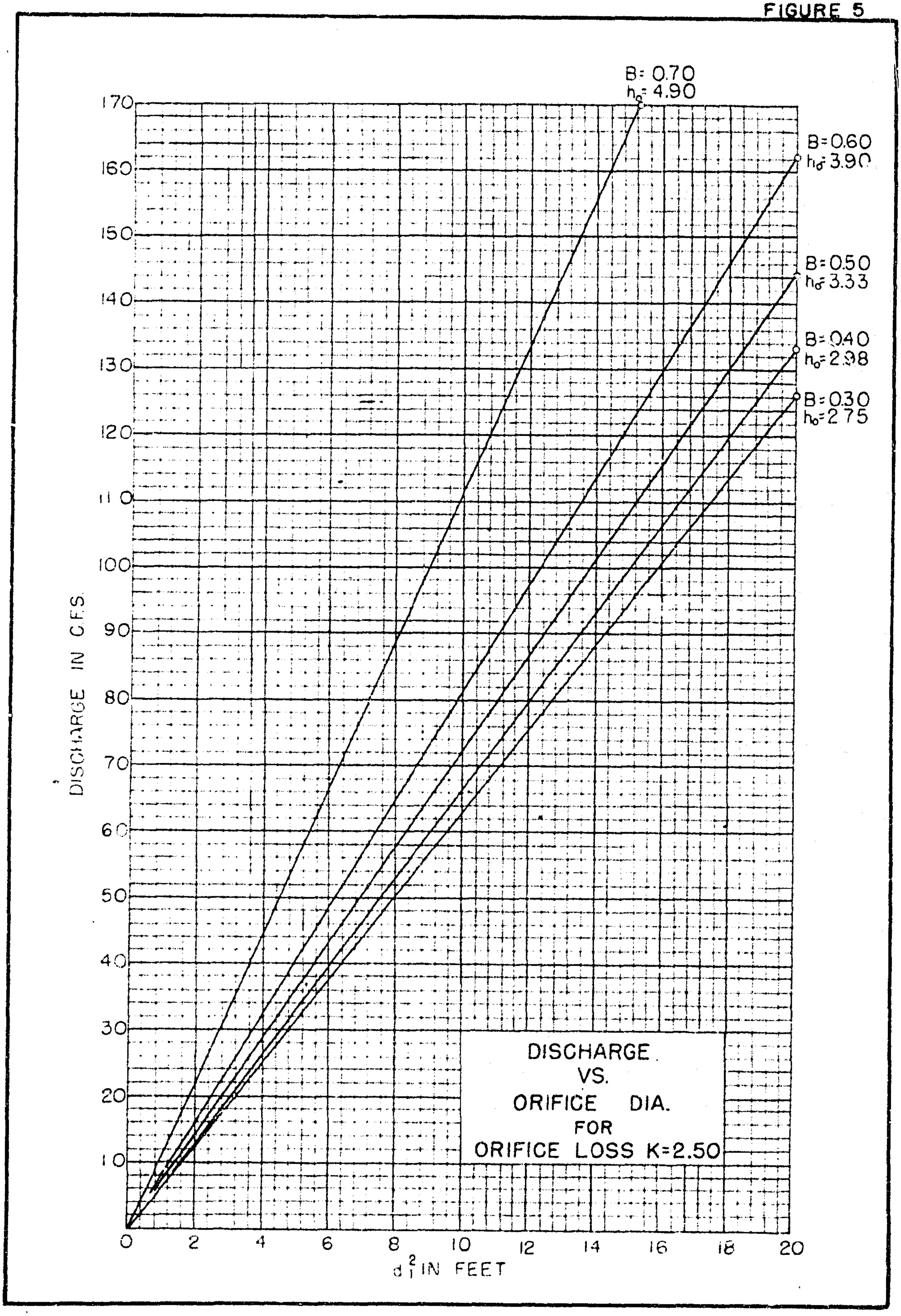
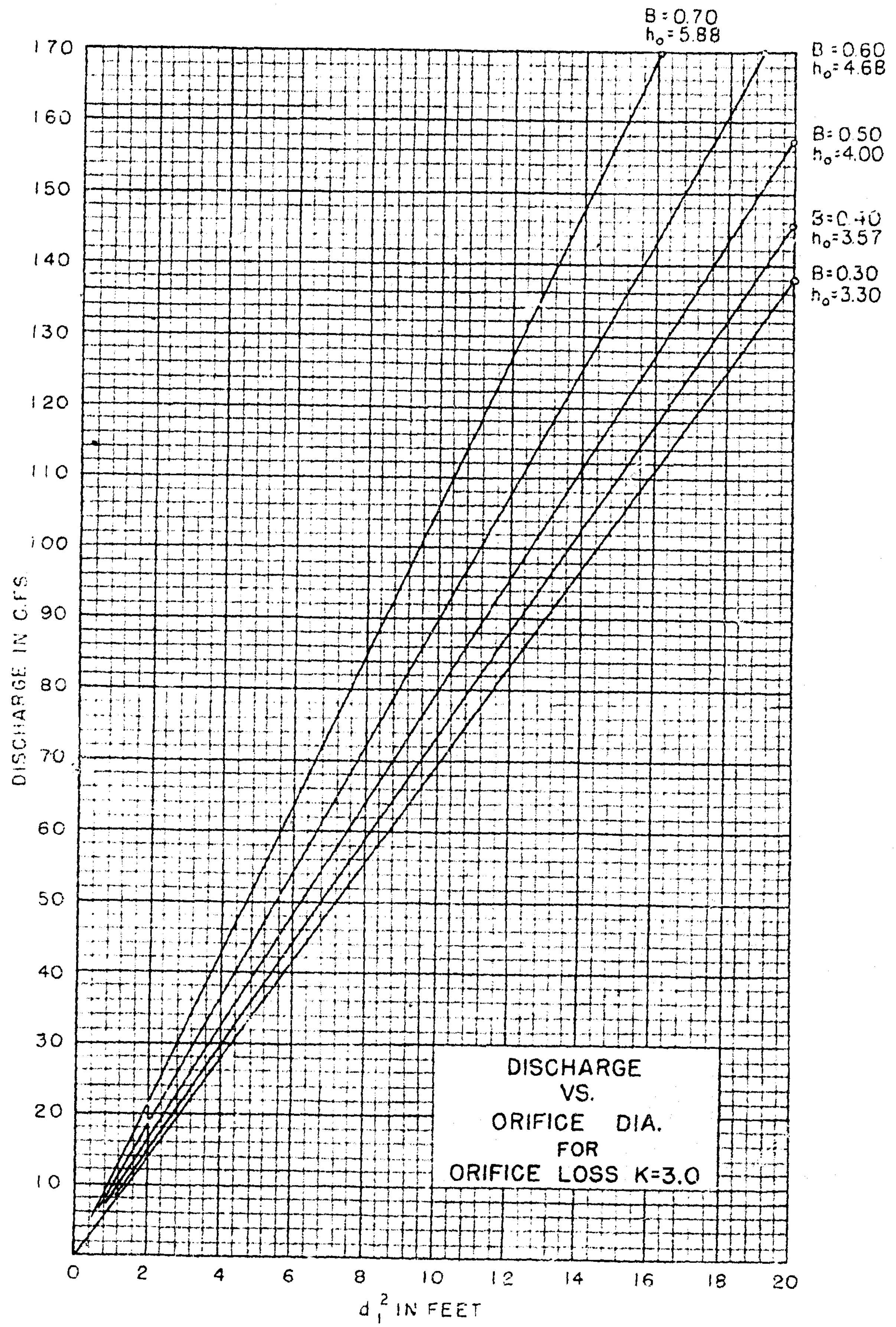

B: 0.70
h_o: 4.90
B=0.60
h_o=3.90
B=0.50
h_o=3.33
B=0.40
h_o=2.98
B=0.30
h_o=2.75
DISCHARGE IN C.F.S.
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
d_1^2 IN FEET
DISCHARGE
VS.
ORIFICE DIA.
FOR
ORIFICE LOSS K=2.50

FIGURE 6


B = 0.70
h_o = 5.88
B = 0.60
h_o = 4.68
B = 0.50
h_o = 4.00
B = 0.40
h_o = 3.57
B = 0.30
h_o = 3.30
DISCHARGE IN C.F.S.
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
d_1^2 IN FEET
DISCHARGE
VS.
ORIFICE DIA.
FOR
ORIFICE LOSS K=3.0